US010051409B2

(12) **United States Patent**
Wigren et al.

(10) **Patent No.: US 10,051,409 B2**
(45) **Date of Patent: Aug. 14, 2018**

(54) **POSITIONING SYSTEMS AND METHODS FOR DETERMINING THE LOCATION OF A MOBILE COMMUNICATION DEVICE**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/606,287**

(22) Filed: **Jan. 27, 2015**

(65) **Prior Publication Data**

US 2016/0219396 A1 Jul. 28, 2016

(51) **Int. Cl.**

G01S 5/02	(2010.01)
H04W 64/00	(2009.01)
H04W 4/02	(2018.01)
H04W 24/08	(2009.01)
H04W 88/08	(2009.01)

(52) **U.S. Cl.**

CPC ***H04W 4/02*** (2013.01); ***G01S 5/02*** (2013.01); ***H04W 24/08*** (2013.01); ***H04W 64/00*** (2013.01); *H04W 88/085* (2013.01)

(58) **Field of Classification Search**

CPC H04W 64/00; H04W 4/04
USPC 455/456.1–456.6; 370/254; 709/224
See application file for complete search history.

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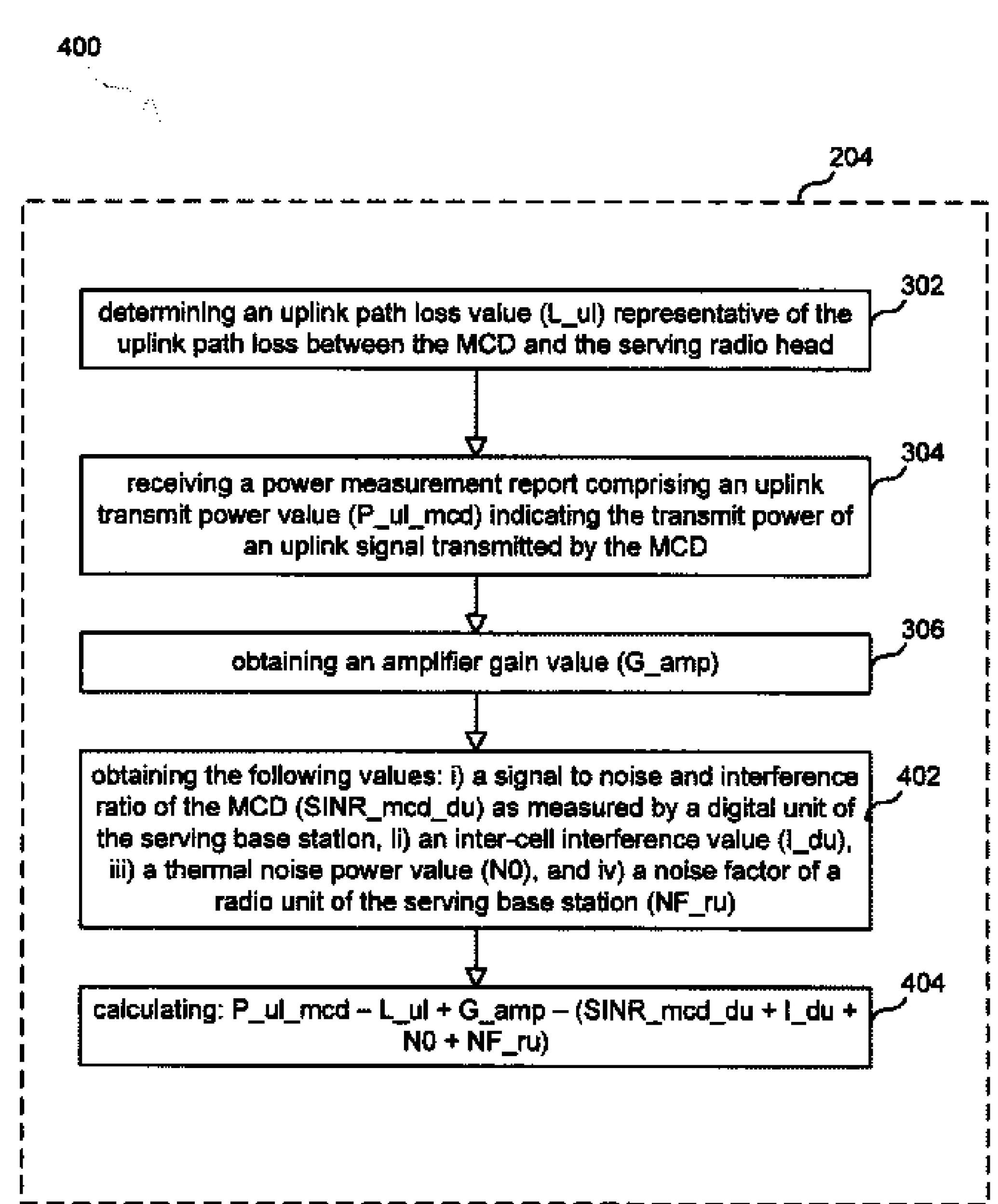
(57) **ABSTRACT**

A localization approach based on cable length detection. In one aspect, a method performed by a positioning system for determining the location of a mobile communication device (MCD) is provided. In some embodiments, the method includes the positioning system determining a cable length value representative of the length of the cable connecting a base station to a radio head serving the MCD. The positioning system then determines a location of the MCD based on the determined cable length.

11 Claims, 8 Drawing Sheets



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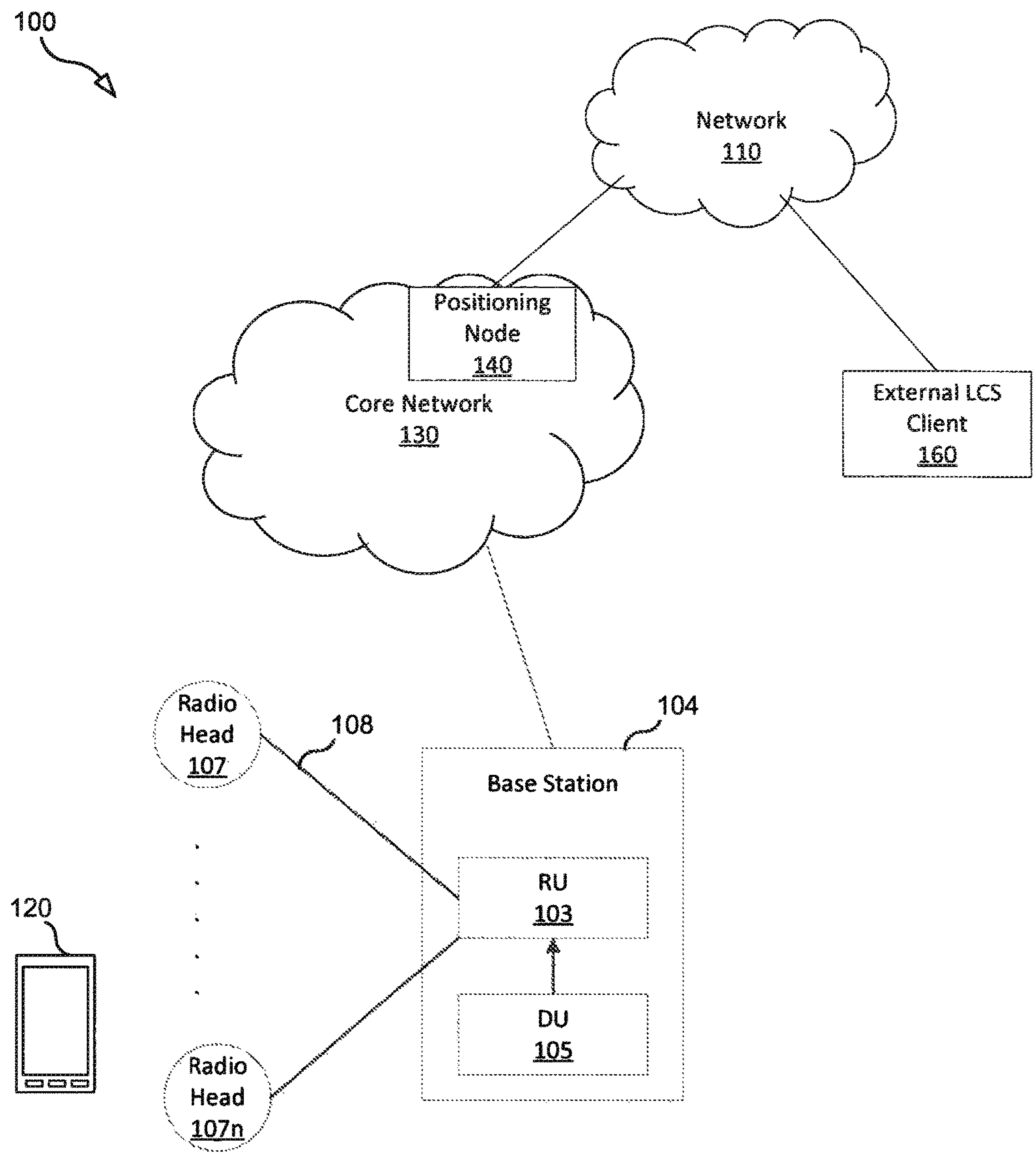
100
Network
110
Positioning
Node
140
Core Network
130
External LCS
Client
160
Radio
Head
107
108
104
Base Station
RU
103
DU
105
120
Radio
Head
107n

FIG. 1

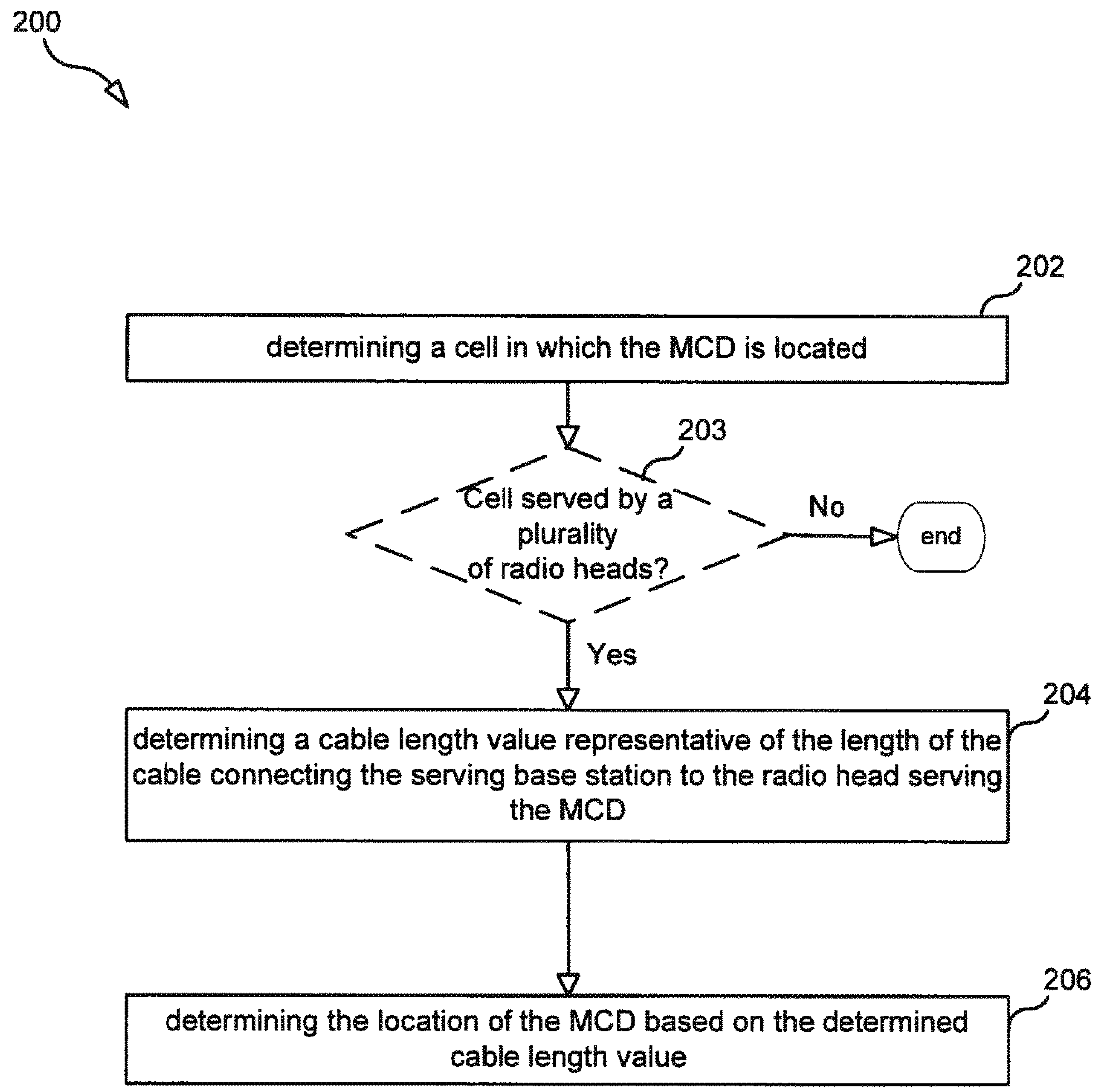
200
202
determining a cell in which the MCD is located
203
Cell served by a plurality of radio heads?
No
end
Yes
204
determining a cable length value representative of the length of the cable connecting the serving base station to the radio head serving the MCD
206
determining the location of the MCD based on the determined cable length value

FIG. 2

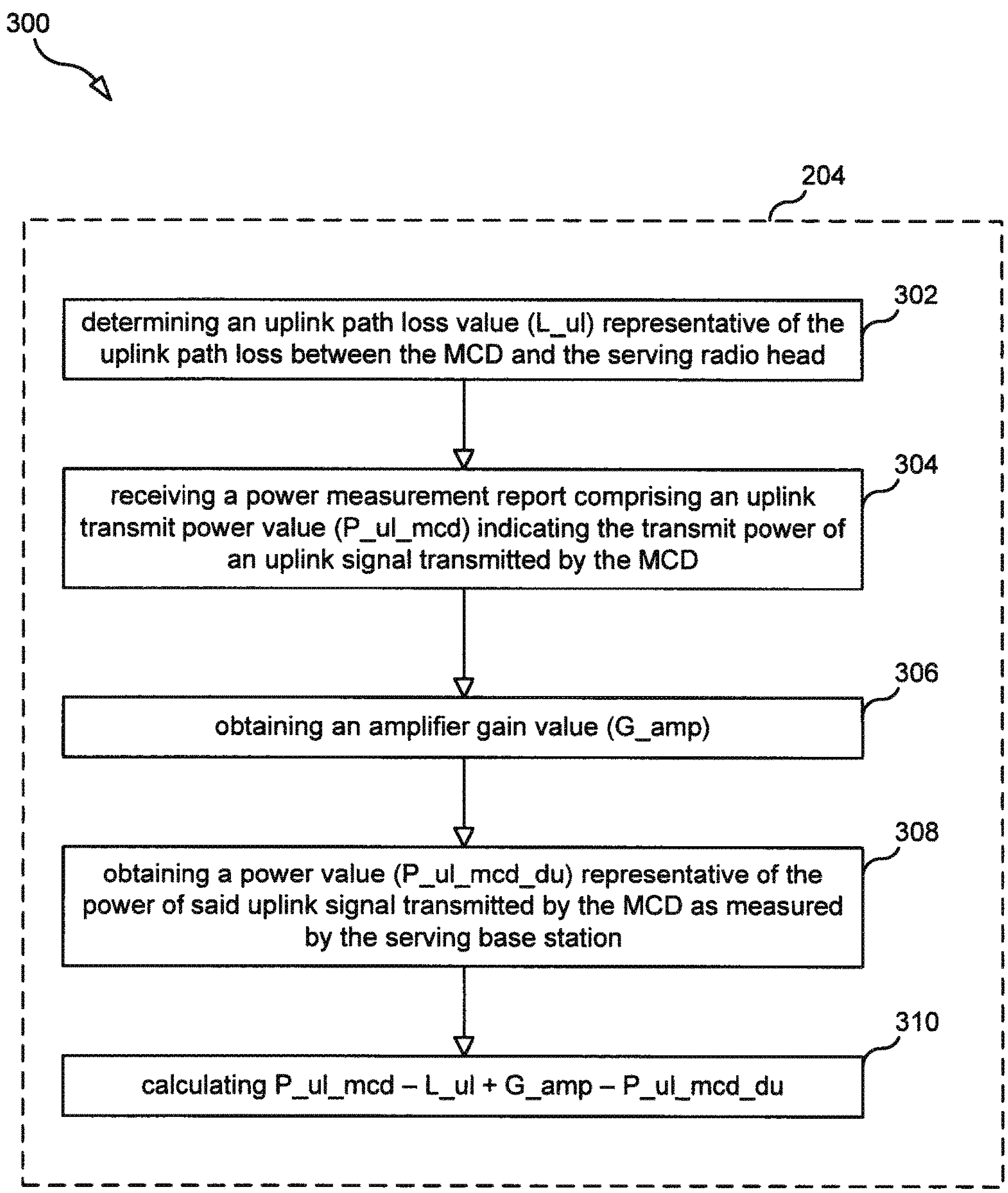
300
204
302
determining an uplink path loss value (L_ul) representative of the uplink path loss between the MCD and the serving radio head
304
receiving a power measurement report comprising an uplink transmit power value (P_ul_mcd) indicating the transmit power of an uplink signal transmitted by the MCD
306
obtaining an amplifier gain value (G_amp)
308
obtaining a power value (P_ul_mcd_du) representative of the power of said uplink signal transmitted by the MCD as measured by the serving base station
310
calculating P_ul_mcd – L_ul + G_amp – P_ul_mcd_du

FIG. 3

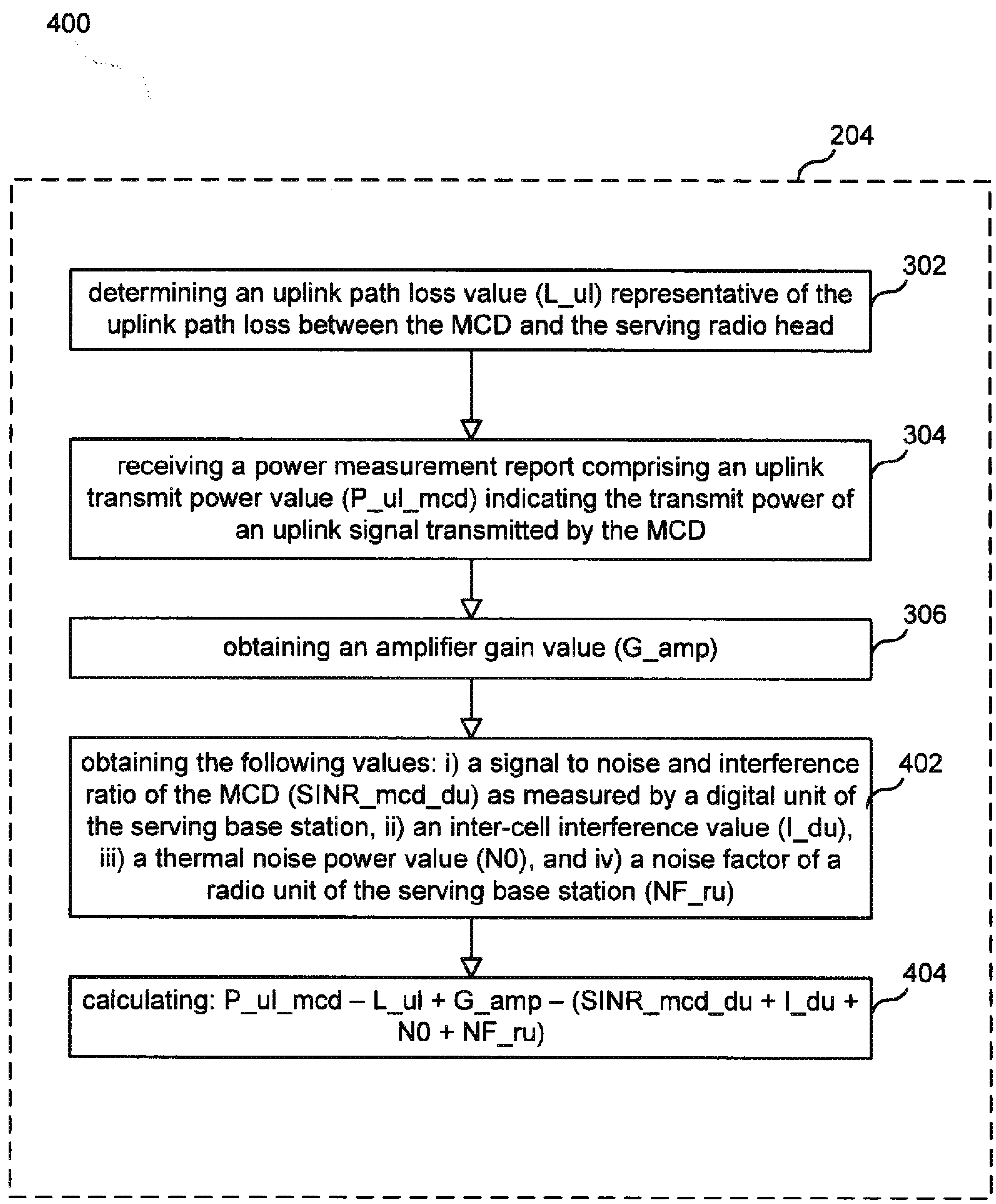
400
204
302
determining an uplink path loss value (L_ul) representative of the uplink path loss between the MCD and the serving radio head
304
receiving a power measurement report comprising an uplink transmit power value (P_ul_mcd) indicating the transmit power of an uplink signal transmitted by the MCD
306
obtaining an amplifier gain value (G_amp)
402
obtaining the following values: i) a signal to noise and interference ratio of the MCD (SINR_mcd_du) as measured by a digital unit of the serving base station, ii) an inter-cell interference value (I_du), iii) a thermal noise power value (N0), and iv) a noise factor of a radio unit of the serving base station (NF_ru)
404
calculating: P_ul_mcd – L_ul + G_amp – (SINR_mcd_du + I_du + N0 + NF_ru)

FIG. 4

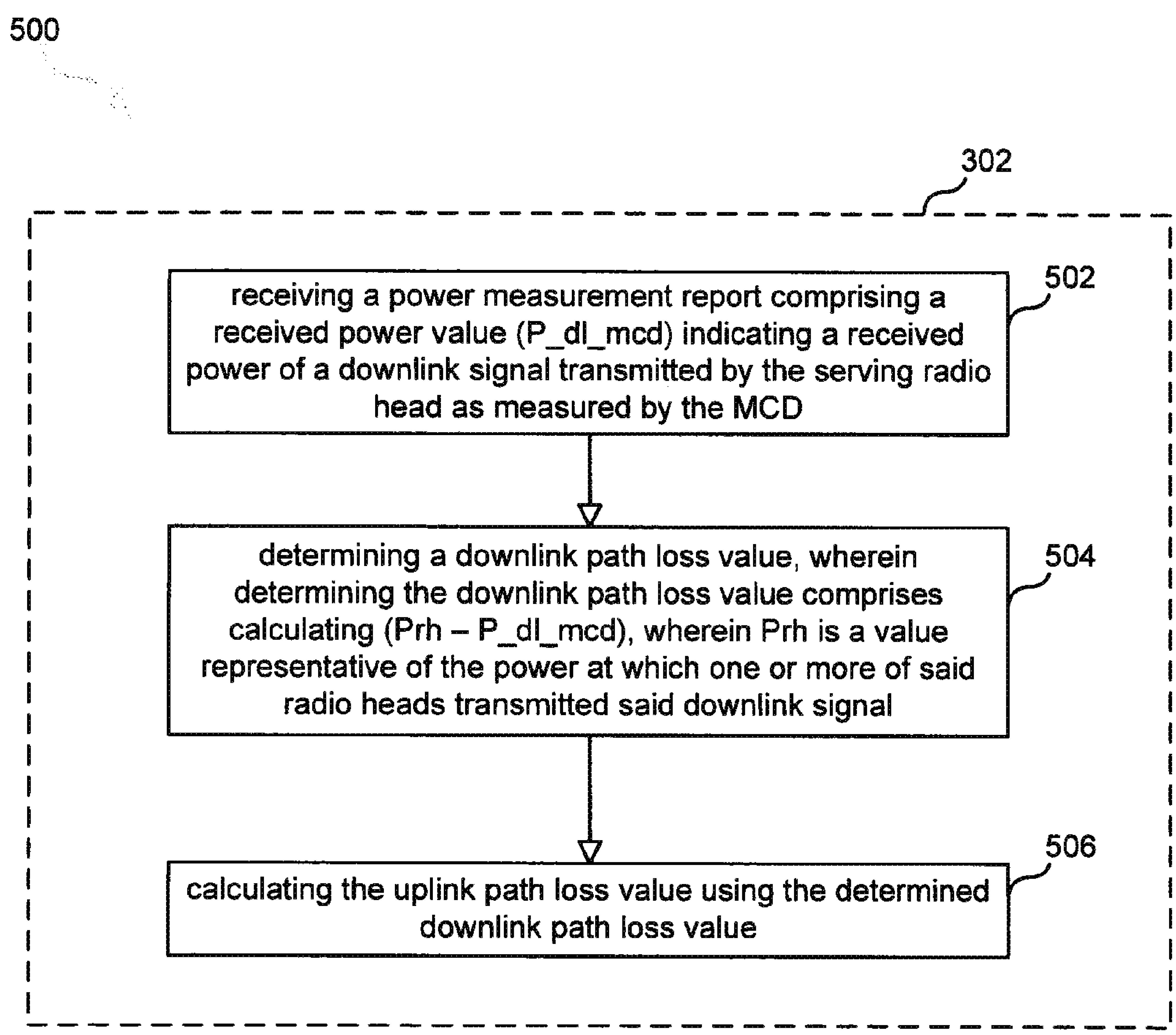
500
302
receiving a power measurement report comprising a received power value (P_dl_mcd) indicating a received power of a downlink signal transmitted by the serving radio head as measured by the MCD
502
determining a downlink path loss value, wherein determining the downlink path loss value comprises calculating (Prh – P_dl_mcd), wherein Prh is a value representative of the power at which one or more of said radio heads transmitted said downlink signal
504
calculating the uplink path loss value using the determined downlink path loss value
506

FIG. 5

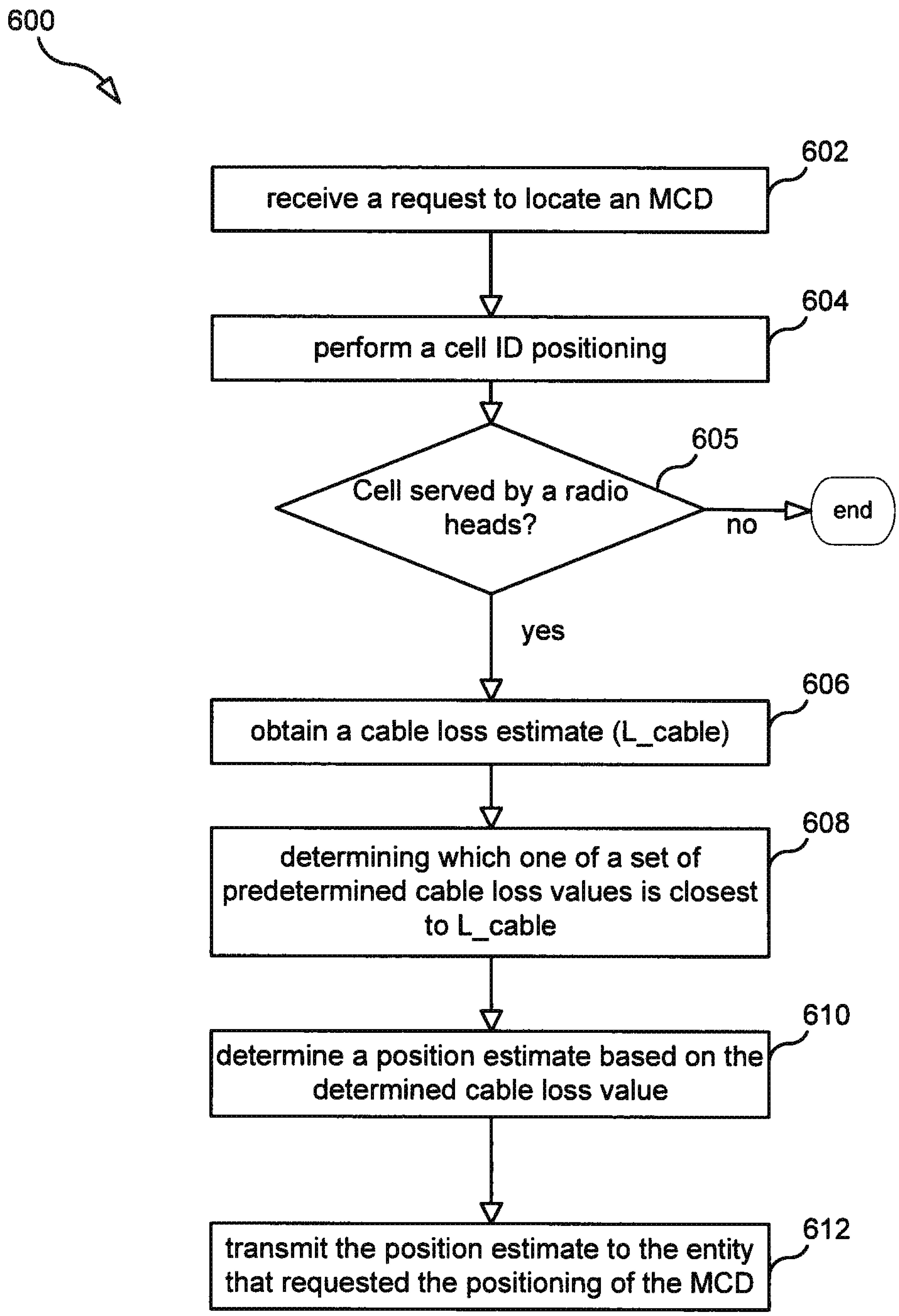
600
receive a request to locate an MCD
602
perform a cell ID positioning
604
Cell served by a radio heads?
605
no
end
yes
obtain a cable loss estimate (L_cable)
606
determining which one of a set of predetermined cable loss values is closest to L_cable
608
determine a position estimate based on the determined cable loss value
610
transmit the position estimate to the entity that requested the positioning of the MCD
612

FIG. 6

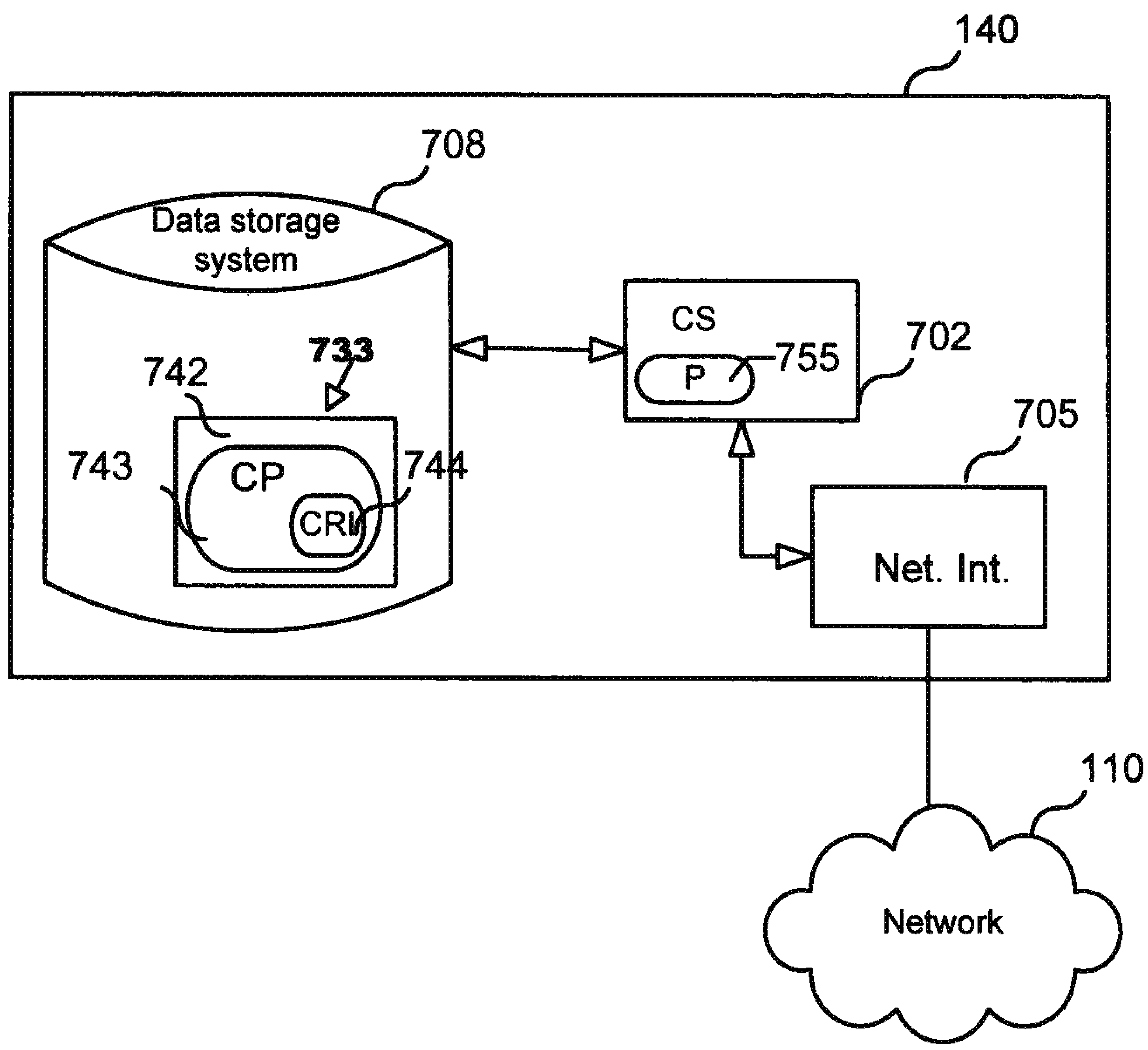
140
708
Data storage system
733
742
743
CP
CRI
744
CS
P
755
702
705
Net. Int.
110
Network

FIG. 7

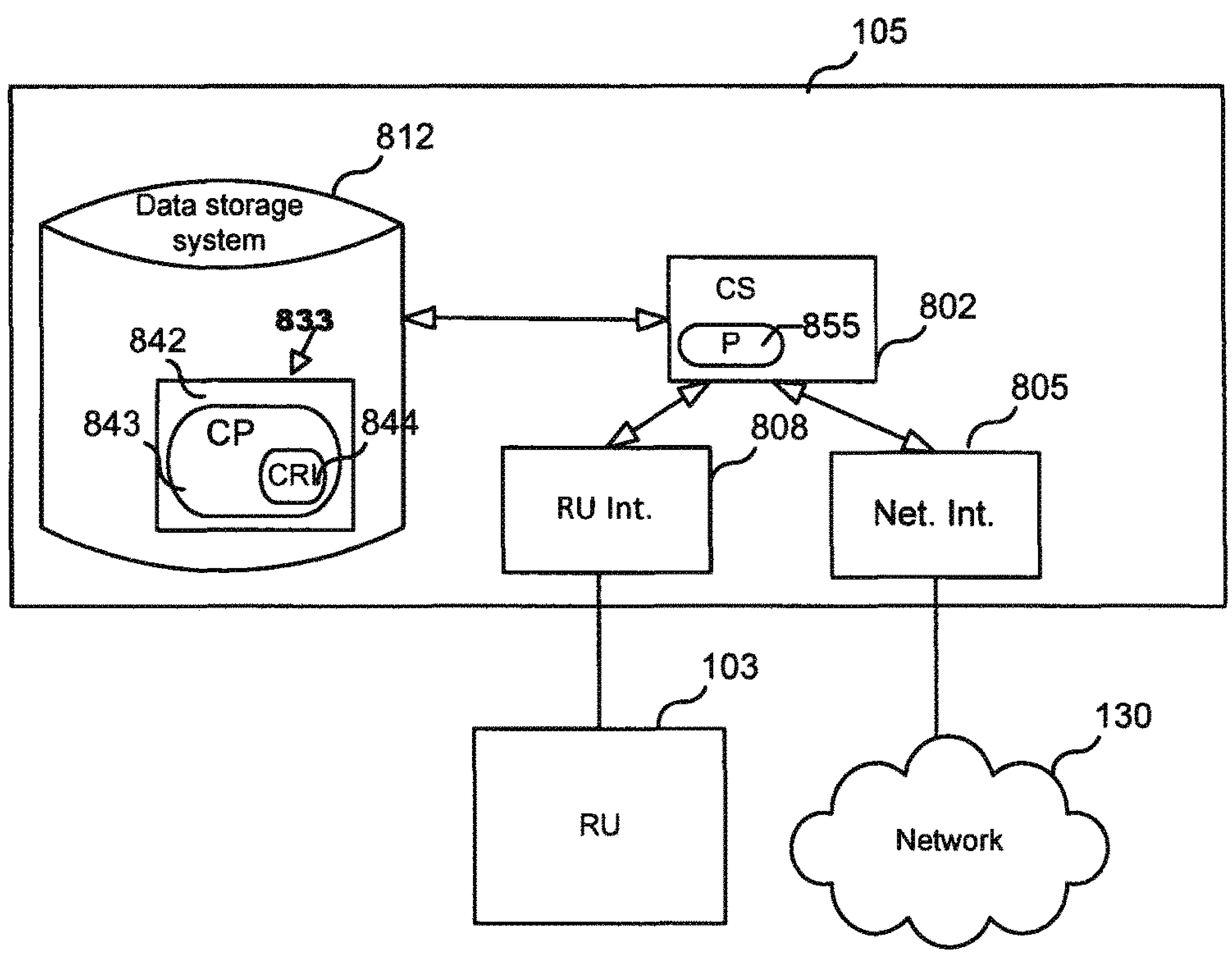
105
812
Data storage system
833
842
843
CP
CRI
844
CS
P
855
802
805
808
RU Int.
Net. Int.
103
RU
130
Network

FIG. 8

POSITIONING SYSTEMS AND METHODS FOR DETERMINING THE LOCATION OF A MOBILE COMMUNICATION DEVICE

TECHNICAL FIELD

This disclosure relates to determining the location of a mobile communication device.

BACKGROUND

A cellular communication system is divided into cells, each of which is served by one specific base station. Each base station, however, may serve one or more cells. The base station functions to communicate with mobile communication devices (MCDs) (e.g., smartphones, tables, phablets, etc.) to provide the MCD with access to a network (e.g., the Internet or other network). A base station typically includes one or more radio units (RU) and a digital unit (DU). An RU typically includes a receiver and a transmitter in order to transmit data to and receive data from an MCD.

The signal transmitted by a base station may be received by an MCD with poor quality when the MCD is in certain locations. For example, when an MCD is located indoors (e.g., in an office building) and the base station that is serving the MCD is located outdoors, the MCD may not receive a strong signal from the base station. Likewise, in such a situation, in order for the MCD to transmit a signal to the base station, the MCD may have transmit the signal using more power than the MCD would have had to use had the MCD been located outdoors. Such a situation reduces the MCD's battery life.

A solution to this problem is to install small transceiver units (a.k.a., "radio heads") indoors and connect each of the radio heads to the RU of a base station using a cable (e.g., local area network (LAN) cable, such as an Ethernet cable). For example, in a large building with poor network coverage, a radio head connected via a cable to an RU may be placed on each floor of the building. Such a radio head receives via the cable a signal transmitted from the RU and then retransmits the signal wirelessly so that the signal will be received with good quality by an MCD located in the vicinity of the radio head. Likewise, when the MCD transmits a wireless signal, the signal is picked up by the radio head in the vicinity of the MCD and retransmitted by the radio head to the RU via the cable. In this way, a base station can provide good indoor coverage. Accordingly, radio heads include one or more antenna elements for broadcasting and receiving wireless signals, and radio heads may also include amplifiers so that a received signal (e.g., a signal from an RU or a wireless signal from an MCD) can be amplified before it is retransmitted.

One such commercial solution is the Ericsson "Radio Dot System" (RDS). In an RDS, multiple (e.g., one to eight) radio heads are each connected to an RU via an Ethernet cable. The radio heads receive power as well as the communication signals via the cable. In the downlink, each such radio head transmits with a maximum power of 100 mW. Power amplifiers are located in the radio head.

Emergency positioning needs (e.g., E-911) and other location services (LCS) require the position of an MCD to be determined within certain horizontal and vertical accuracies. For example, emergency position requirements may require horizontal inaccuracy to be below 50 meters. Additionally, the vertical inaccuracy requirement has recently been tightened to 3 meters in North America in order to better distinguish between floors in buildings.

Accordingly, there is a need for an improved system for determining the location of an MCD.

SUMMARY

The fulfilment of emergency positioning requirements when an MCD is located indoors remains a challenging problem. For example, satellite positioning is not always available indoors. Additionally, cell ID positioning (i.e., determining the location of the MCD based on the cell ID of the cell in which the MCD is located) may not be accurate enough to meet the stringent emergency positioning needs. Thus, there exists a need to improve positioning of an MCD, particular when the MCD is located indoors.

This disclosure relates to systems and methods for determining the location of an MCD. In one aspect, a method is performed by a positioning system for determining the location of the MCD. The positioning system includes one or more of: a positioning node and a base station. The method includes the step of determining a cell in which the MCD is located (e.g., receiving a message including a cell identifier (cell ID) identifying the cell in which the MCD is located). The determined cell is served by a serving base station connected to a set of radio heads. Each one of the radio heads included in the set of radio heads is connected to the base station via a cable. One of the radio heads included in the set is serving the MCD. The method further includes determining a cable length value representative of the length of the cable connecting the base station to the radio head serving the MCD. The method further includes determining the location of the MCD based on the determined cable length value. For example, each radio head connected to the base station may be connected to the base station by a different length cable. Thus, determining a value that represents (e.g., corresponds to) the length of the cable that connects the serving radio head to the base station provides information as to which specific radio head is serving the MCD. Thus, each cable length value can be mapped to the coverage region of a specific radio head (e.g., a floor of a building). Accordingly, the location can be determined with improved accuracy compared to traditional cell id positioning.

In some embodiments, determining the cable length value includes calculating a cable loss value (L_cable) representative of signal attenuation caused by the cable connecting the serving radio head to the serving base station.

In some embodiments, determining the cable loss value includes determining an uplink path loss value (L_ul) representative of the uplink path loss between the MCD and the serving radio head. The method further includes the step of receiving a power measurement report including an uplink transmit power value (P_ul_mcd) indicating the transmit power of an uplink signal transmitted by the MCD. The method further includes the step of obtaining an amplifier gain value (G_amp) representing the gain of an amplifier. The method further includes the step of calculating L_cable using P_ul_mcd, L_ul, and G_amp.

In some embodiments, the step of determining the cable loss value further includes obtaining a power value (P_ul_mcd_du) representative of the power of the uplink signal transmitted by the MCD as measured by the serving base station. In such embodiments, calculating L_cable consists of calculating P_ul_mcd−L_ul+G_amp−P_ul_mcd_du.

In some embodiments, the step of determining the cable loss value further includes obtaining the following values: i) a signal to noise and interference ratio of the MCD (SINR_mcd_du) as measured by a digital unit of the serving base

station, ii) an inter-cell interference value (I_du), iii) a thermal noise power value (N0), and iv) a noise factor of a radio unit of the serving base station (NF_ru). The method further includes the step of calculating P_ul_mcd−L_ul+G_amp−(SINR_mcd_du+I_du+N0+NF_ru). It is noted that all quantities are expressed in the logarithmic domain in this document, thereby allowing addition of powers and gains.

In some embodiments, the step of determining the uplink path loss value includes: receiving a power measurement report transmitted by the MCD, the power measurement report comprising a received power value (P_dl_mcd) indicating a received power of a downlink signal transmitted by the serving radio head as measured by the MCD; determining a downlink path loss value, wherein determining the downlink path loss value comprises calculating (Prh−P_dl_mcd), wherein Prh is a value representative of the power at which one or more of the radio heads transmitted the downlink signal; and obtaining the uplink path loss value based on the downlink path loss value.

In some embodiments, determining the location of the MCD based on the determined cable length value includes the steps of: determining which one of a set of predetermined cable length values is closest to the determined cable length value and estimating the location of the MCD using the predetermined cable length value that was determined to be closest to the determined cable length value.

In another aspect, a positioning system for determining the location of a mobile communication device (MCD) is provided. In some embodiments, the positioning system comprises one or more of: a positioning node; and a base station connected to a set of radio heads, wherein each one of the radio heads included in the set of radio heads is connected to the base station via a cable, and one of the radio heads included in the set is serving the MCD. The positioning system is configured to: determine a cell in which the MCD is located, the determined cell being served by the base station; determine a cable length value representative of the length of the cable connecting the base station to the radio head serving the MCD; and determine the location of the MCD based on the determined cable length value.

The above and other aspects and embodiments are described below.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a block diagram of a positioning system, according to some embodiments.

FIG. **2** is a flow chart of a location method of an MCD, according to some embodiments.

FIG. **3** is a flow chart of a method for determining a cable length value, according to some embodiments.

FIG. **4** is a flow chart of a method for determining a cable length value, according to some embodiments.

FIG. **5** is a flow chart of a method for determining the uplink path loss between an MCD and the serving radio head, according to some embodiments.

FIG. **6** is a flow chart of a location method of an MCD, according to some embodiments.

FIG. **7** is a block diagram of a positioning node apparatus, according to some embodiments.

FIG. **8** is a block diagram of a digital unit apparatus, according to some embodiments.

DETAILED DESCRIPTION

Disclosed herein are systems and methods for determining the location of an MCD that is being served by a radio head by determining a value corresponding to the length of the cable connecting the serving radio head to a base station. A significant advantage of the disclosed systems and methods is that they may provide up to eight times reduced position inaccuracy as compared to cell ID positioning. Additionally, the disclosed techniques can be used to improve the accuracy of Radio Measurements Trace processing servers (TPSs). TPSs play a major role in modern radio access network optimization by using geolocation measurements from MCDs to identify problems in the network. By using the positioning techniques disclosed herein, the position of specific events may be determined with higher accuracy, thereby improving TPS performance.

FIG. **1** is a block diagram of a positioning system **100**, according to some embodiments. The positioning system **100** includes a base station **104**, which comprises a radio unit (RU) **103** and a digital unit (DU) **105**. The RU **103** and the DU **105** may be housed in the same housing or they be housed in separate housings that may or may not be co-located. In some embodiments, such as where the RU **103** and the DU **105** are not coupled in the same housing, DU **103** may be connected to the RU **103** via a cable (e.g., optical, electrical). A plurality of radio heads **107** is connected to base station **104** (more specifically, radio heads **107** are connected to RU **103** of base station **104**). In some embodiments, each radio head **107** is connected via a cable **108**, such as a local area network (LAN) cable (e.g., an Ethernet cable or other LAN cable), to the RU **103**. Radio heads **107** includes one or more antenna elements for wirelessly transmitting signal to an MCD **120** and for wirelessly receiving signal transmitted by MCD **120**. In some embodiments, radio heads **107** may further comprise a power amplifier. In some embodiments, RU **103** may comprise an indoor radio unit (IRU), and radio heads **107** may deliver mobile broadband access to the MCD **120** in a broad range of indoor locations.

Base station **104** may be connected to a core network **130** that includes a positioning node **140** for processing position requests as well as other core network nodes (e.g., a Mobility Management Entity (MME), a Serving Gateway (SGW), and Packet Data Network Gateway (PGW)). However, the embodiments disclosed herein are not limited to any specific type of core network. In embodiments where core network **130** is a core network of a Long Term Evolution (LTE) system, the positioning node **140** may comprise or consist of an Evolved Serving Mobile Location Center (E-SMLC) and the base station **104** may comprise or consist of an enhanced Node B (eNB). In embodiments where core network **130** is a WCDMA 3G cellular system, the positioning node **140** may comprise or consist of a stand-alone Serving Mobile Location Center (SAS) and the base station **104** may comprise or consist of a radio network controller (RNC).

In some embodiments, an LCS client **160** may transmit a positioning request to positioning node **140**. In some embodiments, as shown in FIG. **1**, LCS Client **160** may be a computer server connected to a network (e.g., the Internet), and thus is external to the core network **130**.

In embodiments where core network **130** is an LTE network, a Gateway Mobile Location Center (GMLC) in network **130** may receive from the external LCS client **160** a position request for a particular location services target, e.g., MCD **120**. The GMLC may then transmit the position request to an MME in core network **130**. The MME may in turn forward the request to the positioning node **140** (E-SMLC in this example). The positioning node **140** may then process the location services request to perform a positioning of the target MCD **120**. In some embodiments, the positioning node **140** may perform some or all of the processing for performing the calculations described in connection with FIGS. **2-6**. In other embodiments, the base station **104** may perform some or all of the processing for performing the calculations described below in connection with FIGS. **2-6**. The positioning node may then return the result of the position request back to the MME, which in turn will forward the position result back to requesting LCB client **160** (e.g., through the GMLC and network **110**).

As described below, in situations where MCD **120** is being served by a radio head **107**, positioning node **140** is configured to determine the location of the MCD **120** by determining a value representative of the length of the cable connecting the radio head **107** that is serving MCD **120** to base station **104**.

In the downlink direction, data from the DU **105** is sent to the RU **120** where it is transmitted in analogue form to the radio heads **107**. In the uplink direction, the signal received on each of the radio heads **107** from the MCD **120** is amplified and then sent to the base station **104**. In some embodiments, the gain of the amplifier can be set individually for each radio head **107**. In some embodiments, there may be significant losses (e.g., up to 30 dB) associated with each cable (up to 200 m) connecting the one or more radio heads **107** to the base station **104**. In some embodiments, such loss values may be configured in a database in base station **104**.

In some embodiments, an estimate of the cable loss (L_cable) of the cable **108** connecting base station **104** with the radio head **107** serving the MCD **120** is calculated and then used to determine the location of MCD **102**. The estimated cable loss can be used to determine a position of the MCD because, in many networks, each cable **108** connecting one of the radio heads **107** to base station **104** has a unique cable loss (cable loss is directly proportional to cable length and in many networks each radio head connected to a particular RU of base station **104** is connected by cable having a length that is different than the lengths of the other cables used to connect the other radio heads to the RU). Thus, if the estimated cable loss value is accurate enough, it can be mapped to a specific location because the actual cable lengths (or cable losses) may be measured at installation of the radio heads. Thus, the location of the MCD can be determined more accurately as the cell coverage area may be split up into smaller areas corresponding to each radio head. Furthermore, in embodiments where each radio head is associated with one floor of a building, it may be further possible to resolve location information to a floor of that building.

FIG. **2** is a flow chart of a positioning method **200**, according to some embodiments, performed by a positioning system for determining the location of MCD **120**. In some embodiments, the positioning system comprises one or more of: positioning node **140** and base station **102**.

Referring to FIG. **2**, step **202** includes determining a cell in which MCD **120** is located, the determined cell being served by a serving base station (base station **104**, in this example). As discussed above, cellular systems may be divided into cells, and each cell may be served by one specific base station. In some embodiments, step **202** comprises or consists of the positioning system obtaining a cell identifier (Cell ID) identifying the cell in which the MCD is located (e.g., receiving a message comprising the Cell ID).

In some embodiments, after step **202**, the positioning system determines whether the determined cell is being served by a plurality of radio heads (step **203**). If this is the case, then the process proceeds to step **204**. For example, in step **203** the positioning system may use the Cell ID to obtain a database record from a database, which database record includes information identifying whether or not the determined cell is being served by a plurality of radio heads.

Step **204** includes determining a cable length value (C_length) representative of the length of the cable connecting the serving base station to the radio head serving the MCD. In some embodiments, determining the cable length value consists of determining a cable loss value denoted L_cable. In some embodiments, the positioning node **140** may instruct the base station **104** to perform step **204**.

In step **206**, a location of the MCD is determined based on the determined cable length value. For example, in step **206** an area in which the MCD is likely to be found is determined based on the determined cable length value.

In some embodiments, determining the location of the MCD based on the determined cable length value comprises: obtaining a set of predetermined cable length values; determining which one of a set of predetermined cable length values is closest to the determined cable length value; and estimating the location of the MCD using the predetermined cable length value that was determined to be closest to the determined cable length value.

In some embodiments, estimating the location of the MCD using the predetermined cable length value that was determined to be closest to the determined cable length value comprises using the predetermined cable length value to retrieve location information from a database (e.g., from a table). That is, each of the predetermined cable length values may be stored in a table that maps the predetermined cable length value to a position (e.g., to a floor of a building or a set of coordinates). Thus, determining an estimate of the cable length value allows one to map that information to a specific area (i.e., the entire area served by the serving radio head). In some embodiments, estimating the location of the MCD further comprises obtaining a path loss value representative of a path loss between the MCD and the serving radio head and using the path loss value to estimate the distance between the MCD and the serving radio head. This enables path loss feature enables the positioning system to further narrow the area in which the MCD is likely to be found. Additionally, in some embodiments, an Adaptive Enhanced Cell Identity (AECID) fingerprinting method known in the art could be augmented to take into account location information determined in step **206**.

In some other embodiments, determining the location of the MCD based on the determined cable length value (C_length) comprises: obtaining a set of predetermined cable length values (C_length_pre_i, i=1, 2, . . . , N); determining a subset of the set of predetermined cable length values that are within a certain threshold distance (T) of the determined cable length value; and estimating the location of the MCD using the determined subset of predetermined cable length values. That is, if |C_length_pre_i−C_length|<T, then C_length_pre_i is included in the subset of predetermined cable length values that are used to determine the location of the MCD. In some embodiments, when the subset includes two or more predetermined cable length values, the location of the MCD may be determined to be the union of the coverage areas of the radio heads corresponding to the subset of predetermined cable length values.

In some embodiments, step **204** includes calculating a plurality of cable length values (C_length_i, i=1, 2, . . . , M) (e.g., one cable length value is calculated for each radio head included in the set of radio heads). This could be needed since different radio heads may have different gain settings depending on the cable length. In this embodiment, each of the plurality of predetermined cable length values (i.e., C_length_pre_i) is compared against at least one of the calculated cable length values (C_length_i) in order to determine the predetermined cable length value that is closest to a calculated cable length value. For the case where M=N, one computes:

Argmin [|C_length_i−C_length_pre_i|, i] to determine the predetermined cable length value that is closest to a calculated cable length value. Alternatively, each of the plurality of predetermined cable length values is compared against at least one of the calculated cable length values in order to determine the subset of zero or more predetermined cable length values that are within a threshold distance of a calculated cable length value. As discussed above, this determined subset of predetermined cable length values is used to determine the position of the MCD.

In some embodiments, the set of predetermined cable length values may be obtained by retrieving the set of values from a database using the cell ID of the cell in which the MCD is located. That is, in some embodiments, the database links each cell ID included in a certain set of cell IDs with a set of cable length values. For example, suppose a given cell ID (e.g., cell-id-123) identifies a cell served by an RU of a base station that is connected to a set of radio heads. The database may link the given cell ID with a set of cable length values, where each one of the cable length values represents the length of the cable connecting one of the radio heads to the RU. The database may be hosted by DU **105**, positioning node **140**, or another entity.

In some embodiments, a 90% confidence radius (or other pre-configured confidence limit) may be calculated for every radio head position by calculating the standard deviation of C_length_pre_i around determined C_length. The confidence radius around the radio head will be given as function of Standard deviation of C_length_pre_i shown below in the equation below:

$$RH\_\text{Conf\_Radius}=f(\text{Standard\_deviation}(C\_\text{length\_pre\_}i)).$$

The calculated confidence interval could then be forwarded to a location based service or TPS system in a similar manner as Cell ID, TA, and other methods.

FIG. **3** is a flow chart of a method **300**, according to some embodiments, performed by the positioning system for determining a cable length value. As noted above, the positioning system includes one or more of: positioning node **140** and base station **104**.

In step **302**, an uplink path loss value (L_ul) representative of the uplink path loss between the MCD and the serving radio head is determined. In some embodiments, L_ul may be determined from a calculated downlink path loss (L_dl) value. Thus, in some embodiments, in order to determine L_ul, the positioning node **140** may first order the base station **104** to determine the downlink path loss (L_dl). Determination of the L_ul value from the L_dl value is described in further detail below in connection with FIG. **5**.

In step **304**, a power measurement report comprising an uplink transmit power value (P_ul_mcd) indicating the transmit power of an uplink signal transmitted by the MCD is received. In some embodiments, the MCD **120** may report its uplink transmit power P_ul_mcd. In some embodiments, measurement orders may be transmitted to the MCD **120** from the serving base station **104** for the MCD to report the P_ul_mcd value. In the case of a Trace Processing Server (TPS) geolocation scenario, TPS may utilize 3G/4G Radio Enhanced Statistics (RES) features which turn on measurements on all MCDs to report P_ul_mcd, the uplink transmit power, in measurement reports. These measurements are called UeTxPower measurement, and are reported periodically (e.g., as frequently as every 2 seconds). Thus, the base station **104** may receive the P_ul_mcd value from the base station and perform further processing using that value. In other embodiments, the base station **104** may forward the P_us_mcd value to the positioning node **140** for further processing.

In step **306**, an amplifier gain value is obtained. The amplifier gain value (G_amp) may be set individually for each radio head **107** or each radio head may use the same amplifier gain value. In the latter case, only a single cable length value needs to be calculated, otherwise, in the former case the set of cable length values (C_length_i) is calculated, as described above. In some embodiments, the positioning node **140** and/or base station **104** may obtain G_amp from preconfigured information stored in a database.

In step **308**, the power value representative of the power of the uplink signal transmitted by the MCD as measured by the serving base station (P_ul_mcd_du) is obtained. In some embodiments, the P_ul_mcd_du value can be determined from power headroom reports and the configured maximum value of the MCD **120** power. In some embodiments, the received MCD power (P_ul_mcd_du) is measured directly in the DU **105** of base station **104**, e.g., after de-spreading in a WCDMA network. In some embodiments, the base station **104** sends the P_ul_mcd_du value to the positioning node **140**, for further processing.

In step **310**, P_ul_mcd−L_ul+G_amp−P_ul_mcd_du is calculated. In some embodiments, the positioning node **140** performs the calculation in step **310**. In other embodiments, the base station **104** performs the calculation in step **310**. In some embodiments, the cable loss value for the radio head (L_cable_i) connected to the MCD **120** is calculated according to the equation below:

$$L\_\text{cable\_}i=P\_ul\_mcd-+G\_\text{amp}-P\_ul\_mcd\_du$$

As described above, the cable loss value L_cable_i is representative of the length of the cable connecting the serving base station **104** to the radio head **107** serving the MCD **120**.

FIG. **4** is a flow chart of a method **400** for determining a cable length value, according to other embodiments. In some embodiments, the steps of cable length value determination method **400** may be performed by a positioning node **140**. In other embodiments, the steps of cable length value determination method **400** may be performed by both a positioning node **140** and a base station **104**. Like, method **300**, method **400** includes steps **302-306** (see FIG. **3**).

In step **402**, the following values are obtained: i) a signal to noise and interference ratio of the MCD as measured by a DU of the base station serving the MCD (SINR_mcd_du), ii) an inter-cell interference value (I_du), iii) a thermal noise power value (N0), and iv) a noise factor of a radio unit of the serving base station (NF_ru).

The SINR_mcd_du value is measured by the DU **105** of the serving base station **104**. Thus, in some embodiments, the base station **104** may obtain the SINR_mcd_du value and perform further processing using that value. In some embodiments, the DU **105** of base station **104** may simply transmit the SINR_mcd_du value to the positioning node **140** for further processing.

The N0+NF_ru value may be estimated in the RU **103** of base station **104**. Alternatively, in some embodiments, instead of estimating values of N0+NF_ru, pre-configured values may be used. In other embodiments, different algorithms may be used to estimate the N0+NF_ru value.

One algorithm for estimating the N0+NF_ru value is the sliding window noise floor estimation. Since it may not be possible to obtain exact estimates of this value due to neighbor cell interference, the estimation algorithm applies an approximation using the soft minimum computed over a long window of time. Thus, this estimation relies on the fact that the noise floor may be constant over very long periods of time, disregarding the small temperature drift. However, the sliding window algorithm has a disadvantage of requiring a large amount of storage memory. The amount of storage memory may be particularly troublesome in cases where a large number of instances of the algorithm are needed, which may be the case when interference cancellation is introduced in the uplink.

Another algorithm for estimating the N0+NF_ru value is the recursive noise floor estimation. For example, to reduce the memory consumption of the sliding window algorithm described above, one such recursive algorithm is disclosed in T. Wigren, "Recursive noise floor estimation in WCDMA," IEEE Trans. Vehicular Tech., vol. 69, no. 5, pp. 2615-2620, 2010. The recursive algorithm may reduce the memory requirements of the sliding window algorithm described above by at least a factor of 100.

Thus, the N0+NF_ru value may be estimated by the base station **104** and be used for further processing. In some embodiments, the base station **104** may forward the N0+NF_ru value to the positioning node **140** for further processing.

Once the N0+NF_ru value is obtained, the neighbor cell interference value (I_du) may be determined using the equation shown below.

$$I\_du = P\_mcd\_\mathrm{total} - P\_ul\_mcd\_du - N0\_NF\_ru$$

A more detailed explanation of the calculation of I_du is disclosed in T. Wigren, "Soft uplink load estimation in WCDMA," IEEE Trans. Vehicular Tech., vol. 58, no. 2, pp. 760-772, February 2009, which is incorporated herein by reference.

In step **404**, the following value is calculated, which is representative of the cable loss value of the cable (L_cable_i) connecting the serving base station **104** to the radio head **107** serving the MCD **120**:

$$L\_\mathrm{cable}\_i = P\_ul\_mcd - L\_ul + G\_\mathrm{amp} - (\mathrm{SINR}\_mcd\_du + I\_du + N0 + NF\_ru)$$

Thus, in alternative embodiments, a value representative of (SINR_mcd_du+I_du+N0+NF_ru) may be used in lieu of the P_ul_mcd_du value described above in connection with step **308** of FIG. **3**. The relationship between these two values is shown below:

$$P\_ul\_mcd\_du = \mathrm{SINR}\_mcd\_du + I\_du + N0 + NF\_ru$$

FIG. **5** is a flow chart of a method **500**, according to some embodiments, for determining an uplink path loss value (L_ul) representative of the uplink path loss between the MCD and the serving radio head.

In step **502**, a power measurement report comprising a received power value (P_dl_mcd) indicating a received power of a downlink signal transmitted by the serving radio head as measured by the MCD is received. In some embodiments, the MCD **120** may measure the received power (P_dl_mcd) for the radio head **107** to which it is connected. In some embodiments, measurement orders may be transmitted to the MCD **120** from the serving base station **104** for MCD to measure the P_dl_mcd value. In the case of a TPS geolocation scenario, TPS may utilize 3G/4G RES features which turn on measurements on all MCDs to report $P_{dl\ mcd}$, the downlink transmit power, in measurement reports. These measurements are called UeRxPower measurement and are reported periodically (e.g., as frequently as every 2 seconds). Thus, the MCD **120** may transmit the measured P_dl_mcd value in a measurement report as the UeRxPower to the base station **104**. In some embodiments, base station **104** may send the P_dl_mcd value to the positioning node **140** for determination of L_ul, and in other embodiments, determination of L_ul may be performed by the base station **104**.

In step **504**, a downlink path loss value (L_dl) is determined, wherein the determination comprises calculating (P_dl_mcd−Prh), wherein Prh is a value representative of the power at which the radio head transmitted the downlink signal. In some embodiments, the configured downlink transmit power Prh may be known for each radio head **107**. Thus, a downlink path loss value (L_dl) may be determined according to the equation below:

$$L\_dl = P\_rh - P\_dl\_mcd$$

In embodiments where all radio heads have a different power (Prh_i) in the downlink signal, the L_dl_i value may be determined according to the equation below:

$$L\_dl\_i = Prh\_i - P\_dl\_mcd$$

Alternatively, in some embodiments, a dedicated measurement may be used for L_dl.

In step **506**, the uplink path loss value is calculated using the determined downlink path loss value. Thus, in some embodiments the uplink path loss value (L_ul) may be determined from the downlink path loss (L_dl) value determined in step **504**. In some embodiments, once the L_dl value is determined, the positioning node **140** may then order the base station **104** to perform a measurement of the uplink path loss (L_ul). Alternatively, the positioning node **140** may perform a measurement of the uplink path loss. In some embodiments, it may be assumed (for simplicity) that the propagation conditions of the uplink are similar to those of the downlink, and thus L_ul=L_dl. For example, in the case of time division duplex, the reciprocity of the propagation can be used to motivate why L_ul=L_dl.

Alternatively, in the case of frequency division duplex, a calculation that is correct on average may be made to conclude a functional dependence between L_ul and L_dl. In such scenarios, a compensation value depending on the carrier frequency ($f_{carrier}$) is typically needed. Thus, the following general relation shown in the equation below may be assumed to hold:

$$L\_ul = F(L\_dl, f\_\mathrm{carrier})$$

The above relation may have errors; however, these errors may be assumed to be small as compared to the cable loss variation that may approach 30 dB for the Ethernet cable technology used with certain small cell systems, such as DTS.

FIG. **6** is a flow chart of a location method **600**, according to some embodiments. Method **600** may be performed by the positioning node **140** and/or the base station **104**.

In step **602**, a request is received to locate an MCD. For example, in some embodiments, the location request may be submitted by a LCS client **160** to the positioning node **140**, potentially through one or more intermediaries as described above. In some embodiments, once the positioning node **140** receives the location request.

In step **604**, a cell ID positioning is performed. For example, the positioning system obtains a cell ID identifying the cell in which the MCD is located.

In step **605**, based on the obtained cell ID, a determination is made as to whether the cell identified by the cell ID is served by a plurality of radio heads connected to a base station. If yes, the process continues to step **606**, otherwise the process ends.

In step **606**, a cable loss estimate (L_cable) is obtained. The cable loss estimate L_cable value may be obtained by the positioning node **140** and/or the base station **104** as described above in connection with FIGS. **3-4**.

In step **608**, a determination is made as to which one of a set of predetermined cable loss values is closest to L_cable. The determination made be made by the base station **104** and/or the positioning node **140**.

In step **610**, a position estimate is determined based on the determined cable loss value (L_cable). The position estimate is determined by the base station **104** and/or the positioning node **140** as described above in connection with step **206** of FIG. **2**.

In step **612**, the position estimate is transmitted to the entity that requested the positioning of the MCD. For example, in some embodiments, the base station **104** and/or the positioning node **140** may transmit the positioning of the MCD **120** to the original LCS client **160** that submitted the location request.

FIG. **7** is a block diagram of a positioning node apparatus, such as positioning node **140**. As shown in FIG. **7**, positioning node apparatus **140** may include or consist of: a computer system (CS) **702**, which may include one or more processors **755** (e.g., a microprocessor) and/or one or more circuits, such as an application specific integrated circuit (ASIC), field-programmable gate arrays (FPGAs), a logic circuit, and the like; a network interface **705** for connecting apparatus **104** to a network **110**; and a data storage system **708**, which may include one or more non-volatile storage devices and/or one or more volatile storage devices (e.g., random access memory (RAM)).

In embodiments where apparatus **140** includes a processor **755**, a computer program product (CPP) **733** may be provided. CPP **733** includes or is a computer readable medium (CRM) **742** storing a computer program (CP) **743** comprising computer readable instructions (CRI) **744** for performing steps described herein (e.g., one or more of the steps shown in FIGS. **2-6**). CP **743** may include an operating system (OS) and/or application programs. CRM **742** may include a non-transitory computer readable medium, such as, but not limited, to magnetic media (e.g., a hard disk), optical media (e.g., a DVD), solid state devices (e.g., random access memory (RAM), flash memory), and the like.

In some embodiments, the CRI **744** of computer program **743** is configured such that when executed by computer system **702**, the CRI causes the apparatus **740** to perform steps described above (e.g., steps described above and below with reference to the flow charts shown in the drawings). In other embodiments, positioning node apparatus **140** may be configured to perform steps described herein without the need for a computer program. That is, for example, computer system **702** may consist merely of one or more ASICs. Hence, the features of the embodiments described herein may be implemented in hardware and/or software.

FIG. **8** is a block diagram of DU **105**, according to some embodiments. As shown in FIG. **4**, DU apparatus **105** may include or consist of: a computer system (CS) **802**, which may include one or more processors **855** (e.g., a microprocessor) and/or one or more circuits, such as an application specific integrated circuit (ASIC), field-programmable gate arrays (FPGAs), a logic circuit, and the like; a network interface **805** for connecting DU **105** to network **130**; one or more RU interfaces **808** for connecting DU **105** to one more RUs; and a data storage system **812**, which may include one or more non-volatile storage devices and/or one or more volatile storage devices (e.g., random access memory (RAM)). In some embodiments, network interface **805** and RU interface **808** include a transceiver for transmitting data and receiving data.

In embodiments where DU apparatus **105** includes a processor **855**, a computer program product (CPP) **833** may be provided. CPP **833** includes or is a computer readable medium (CRM) **842** storing a computer program (CP) **843** comprising computer readable instructions (CRI) **844** for performing steps described herein (e.g., one or more of the steps shown in FIGS. **2-6**). CP **843** may include an operating system (OS) and/or application programs. CRM **842** may include a non-transitory computer readable medium, such as, but not limited, to magnetic media (e.g., a hard disk), optical media (e.g., a DVD), solid state devices (e.g., random access memory (RAM), flash memory), and the like.

In some embodiments, the CRI **844** of computer program **843** is configured such that when executed by computer system **802**, the CRI causes the apparatus **105** to perform steps described above (e.g., steps described above and below with reference to the flow charts shown in the drawings). In other embodiments, apparatus **105** may be configured to perform steps described herein without the need for a computer program. That is, for example, computer system **802** may consist merely of one or more ASICs. Hence, the features of the embodiments described herein may be implemented in hardware and/or software.

While various embodiments have been described above, it should be understood that they have been presented by way of example only, and not limitation. Thus, the breadth and scope of the present invention should not be limited by any of the above-described exemplary embodiments. Moreover, any combination of the above-described elements in all possible variations thereof is encompassed by the invention unless otherwise indicated herein or otherwise clearly contradicted by context.

Additionally, while the processes described above and illustrated in the drawings are shown as a sequence of steps, this was done solely for the sake of illustration. Accordingly, it is contemplated that some steps may be added, some steps may be omitted, the order of the steps may be re-arranged, and some steps may be performed in parallel.

Abbreviations

RH_i=Radio head i of a maximum of n.
P_ul_mcd=The uplink transmit power as measured by the MCD [dBw].
P_dl_mcd=The measured received power in the downlink as measured by the MCD [dBw]
L_ul=The uplink path loss between the MCD and the serving radio head [dB].
L_dl=The downlink path loss between the serving radio head and the MCD [dB].
Prh=The transmit power of the radio head [dBw].
G_amp=The gain of the uplink amplifier of the radio head [dB].
L_cable=The determined cable loss [dB].
NF_ru=The noise factor of the RU [dB].
SINR_mcd_du=The signal to noise and interference ratio of the MCD, as measured in the DU [dB]
P_ul_mcd_du=The MCD power, as measured in the DU [dBw].
P_mcd_total=the total power of the MCD

N0=Thermal noise power [dBw].
I_du=Inter-cell interference [dBw].
C_length=a cable length value

The invention claimed is:

1. A method performed by a positioning system for determining a location of a mobile communication device (MCD), the method comprising:
- determining a cell in which the MCD is located, said determined cell being served by a base station connected to a set of radio heads, wherein each one of the radio heads included in said set of radio heads is connected to the base station via a cable, and one of said radio heads included in said set is serving the MCD;
- calculating a cable loss value (L_cable) representative of signal attenuation caused by the cable connecting the serving radio head to the base station; and
- determining the location of the MCD based on L_cable, wherein
- calculating L_cable comprises:
  - determining an uplink path loss value (L_ul) representative of the uplink path loss between the MCD and the serving radio head,
  - receiving a power measurement report comprising an uplink transmit power value (P_ul_mcd) indicating the transmit power of an uplink signal transmitted by the MCD,
  - obtaining an amplifier gain value (G_amp) representing the gain of an uplink amplifier of the serving radio head,
  - at least one of (a) obtaining a power value (P_ul_mcd_du) representative of the power of said uplink signal transmitted by the MCD as measured by the base station or (b) obtaining the following values: i) a signal to noise and interference ratio of the MCD (SINR_mcd_du) as measured by a digital unit of the base station, ii) an inter-cell interference value (I_du), iii) a thermal noise power value (N0), and iv) a noise factor of a radio unit of the base station (NF_ru), and
  - calculating the L_cable comprises calculating at least one of: P_ul_mcd−L_ul+G_amp+P_ul_mcd_du or P_ul_mcd−L_ul+G_amp−(SINR_mcd_du+I_du+N0+NF_ru).

2. The method of claim 1, wherein the step of determining the uplink path loss value comprises:
- receiving a power measurement report transmitted by the MCD, the power measurement report comprising a received power value (P_dl_mcd) indicating a received power of a downlink signal transmitted by the serving radio head as measured by the MCD;
- determining a downlink path loss value, wherein determining the downlink path loss value comprises calculating (Prh−P_dl_mcd), wherein Prh is a value representative of the power at which one or more of said radio heads transmitted said downlink signal; and
- obtaining the uplink path loss value based on the downlink path loss value.

3. The method of claim 1, wherein determining the cell in which the MCD is located comprises receiving a message comprising a cell identifier (cell ID) identifying the cell in which the MCD is located.

4. The method of claim 1, wherein the positioning system comprises one or more of: the base station and a positioning node.

5. The method of claim 1, wherein determining the location of the MCD based on the determined cable loss value comprises:
- determining a cable length value based on the cable loss value, the cable length value representative of the length of the cable connecting the base station to said radio head serving the MCD;
- determining which one of a set of predetermined cable length values is closest to the determined cable length value; and
- estimating the location of the MCD using the predetermined cable length value that was determined to be closest to the determined cable length value.

6. The method of claim 1, wherein
- determining the cell in which the MCD is located comprises obtaining an cell identifier (Cell ID) identifying the cell in which the MCD is located, and
- the method further comprises using the Cell ID to determine whether the cell identified by the Cell ID is being served by a plurality of radio heads.

7. A positioning system for determining a location of a mobile communication device (MCD), said positioning system comprising one or more of:
- a positioning node; and
- a base station connected to a set of radio heads, wherein each one of the radio heads included in said set of radio heads is connected to the base station via a cable, and one of said radio heads included in said set is serving the MCD
- the positioning system is configured to:
- determine a cell in which the MCD is located, said determined cell being served by the base station;
- calculate a cable loss value (L_cable) representative of signal attenuation caused by the cable connecting the serving radio head to the base station; and
- determine the location of the MCD based on L_cable, wherein
- calculate the L_cable comprises:
  - determining an uplink path loss value (L_ul) representative of the uplink path loss between the MCD and the serving radio head;
  - obtaining an uplink transmit power value (P_ul_mcd) indicating the transmit power of an uplink signal transmitted by the MCD;
  - obtaining an amplifier gain value (G_amp) representing the gain of an uplink amplifier of the serving radio head;
  - at least one of (a) obtaining a power value (P_ul_mcd_du) representative of the power of said uplink signal transmitted by the MCD as measured by the base station or (b) obtaining the following values: i) a signal to noise and interference ratio of the MCD (SINR_mcd_du) as measured by a digital unit of the base station, ii) an inter-cell interference value (I_du), iii) a thermal noise power value (N0), and iv) a noise factor of a radio unit of the base station (NF_ru); and
  - calculate L cable by calculating at least one of: P_ul_mcd−L_ul+G_amp−P_ul_mcd_du or P_ul_mcd−L_ul+G_amp−(SINR_mcd_du+I_du+N0+NF_ru).

8. The positioning system of claim 7, wherein the positioning system is further configured to:
- obtain a received power value (P_dl_mcd) indicating a received power of a downlink signal transmitted by the serving radio head as measured by the MCD;
- determine a downlink path loss value, wherein determining the downlink path loss value comprises calculating

(Prh−P_dl_mcd), wherein Prh is a value representative of the power at which one or more of said radio heads transmitted said downlink signal; and

obtain the uplink path loss value based on the downlink path loss value.

9. The positioning system of claim **7**, wherein the positioning system is configured to determine the cell in which the MCD is located by obtaining a cell identifier (cell ID) identifying the cell in which the MCD is located.

10. The positioning system of claim **7**, wherein the positioning system is further configured to:

determine a cable length value based on the cable loss value, the cable length value representative of the length of the cable connecting the base station to said radio head serving the MCD;

determine which one of a set of predetermined cable length values is closest to the determined cable length value; and

estimate the location of the MCD using the predetermined cable length value that was determined to be closest to the determined cable length value.

11. The positioning system of claim **7**, wherein

the positioning system is configured to determine the cell in which the MCD is located comprising by obtaining an cell identifier (Cell ID) identifying the cell in which the MCD is located, and

the positioning system is further configured to use the Cell ID to determine whether the cell identified by the Cell ID is being served by a plurality of radio heads.

* * * * *